REFRACTIVE PROJECTION OBJECTIVE WITH A WAIST

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of International Patent Application Serial No. PCT/EP 03/01651 filed February 19, 2003, which claims priority of U.S. Provisional Application Serial No. 60/360,845 filed March 1, 2002 and which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

The invention relates to a projection system for making photographic exposures with a refractive projection objective. More specifically, the invention relates to the refractive projection objective itself as well as to a method involving the use of the projection system with the refractive projection objective in the manufacture of components carrying a microstructure. All lenses of the projection objective consist of the same material, and the numerical aperture of the projection objective on the image side is larger than 0.7.

The German patent application DE 198 18 444 A1 discloses refractive projection objectives that are designed for exposures with light of a wavelength of 248.4 nm, where all lenses of the projection objectives consist of a material which at the stated exposure wavelength have a refractive index of 1.50839 which is characteristic of, e.g., quartz glass.

The aforementioned reference further discloses that when image aberrations occur, they can be corrected by a targeted use of aspheres. For example, as mentioned in this reference, an image distortion occurring with the projection objective can be corrected by using an asphere in the first lens group, which in this case is a lens group of positive refractive power. Further according to the same reference, entrance pupil aberrations occurring in the projection objective can be corrected by including an asphere in the second lens group, which is a group of negative refractive power and forms a first waist of the projection objective. It is also known that by arranging an aspheric lens surface in the third lens group it is possible to minimize a coma effect that may be present in the projection objective, where the third lens group is a group of positive refractive power and is arranged between the two waists (second and fourth lens group).

A coma effect occurring in the objective can likewise be minimized by arranging an asphere in the sixth lens group, which is of positive refractive power and is arranged directly in front of the wafer. Through the use of an asphere in the fifth lens group, which is of positive refractive power, it is possible to correct aberrations associated with a large numerical aperture, in particular spherical aberrations. A correction of spherical aberrations is also possible by arranging an asphere in the fourth lens group, as long as the asphere is arranged close to the image plane.

As disclosed in US 5,668,672, chromatic aberrations can be corrected by using quartz glass in combination with a fluoride material as lens materials. Further known from US 6,377,338 is a refractive projection objective, in which chromatic aberrations are corrected by using a combination of two or more kinds of fluoride crystals. The projection objective shown in Figure 11 of US 6,377,338, which is designed for a wavelength of 157 nm, includes several aspheres. The lens materials proposed for use at this wavelength include in particular calcium fluoride and lithium fluoride.

In the US patent application 09/694,878 (EP 1094350 A), the use of individual calcium fluoride lenses is proposed for

the correction of chromatic aberrations in an objective designed for the wavelength of 193 nm wherein most of the lenses consist of quartz glass. The projection objective presented in Fig. 1 of this reference is a refractive objective with a numerical aperture of 0.7 and includes a lens group of negative power providing a clearly defined waist that is identified in the drawing as G2.

A projection objective that is likewise designed for a wavelength of 193 nm is described in US 6,522,484. This lens system has a numerical aperture of 0.7 and the specified lens materials are quartz glass and calcium fluoride used in combination. The projection objectives proposed in this reference further have at least two lens groups of negative power, each of which produces a clearly defined waist in the light path geometry.

Refractive lens systems are described in EP 1139138 A1, in which the lenses consist of the materials calcium fluoride and quartz glass. An example of an objective designed for a wavelength of 157 nm is shown in which all lenses consist of calcium fluoride. Other lens arrangements presented in the same reference are designed for the wavelength of 193 nm. Each of the lens systems described includes a plurality of aspheres.

Using calcium fluoride, e.g., in a lens system designed for exposures at a wavelength of 193 nm has the disadvantages that on the one hand calcium fluoride is not as readily available as quartz glass and on the other hand it is also significantly more expensive.

OBJECT OF THE INVENTION

The invention therefore has the objective to propose refractive lens arrangements, more specifically a microlithography projection system for making photographic exposures with a refractive projection objective, with a large numerical aperture and good optical qualities.

As a further objective, the invention aims to provide refractive lens systems for use in microlithography which offer a large numerical aperture in combination with small longitudinal chromatic aberrations.

The invention further has the objective to provide refractive lens systems at reduced manufacturing cost.

SUMMARY OF THE INVENTION

According to the invention, the objectives outlined above are met by a refractive projection objective which has an optical axis, an object field, a system diaphragm, and an image field, wherein all lenses of the objective consist of the same material, wherein a maximum lens diameter can be identified among the lenses of the objective, and wherein the image-side numerical aperture of the objective is greater than 0.7. A light bundle traversing the objective from the object field to the image field is defined by the image-side numerical aperture and by the image field, and a maximum light bundle diameter exists relative to the entire light path between the object field and the image field. According to the invention, the objective is designed so that in an axial length interval at least equal to the maximum lens diameter or the maximum light bundle diameter and extending from the diaphragm towards the object field, the light bundle has a diameter that is larger than 85% of the maximum lens diameter or the maximum light bundle diameter.

Due to the measure of specifying the same material for all of the lenses, the manufacturing cost can be lowered even

for the reason alone that the higher costs for procuring different materials are avoided.

The invention also provides a solution for a purely refractive objective which is made with only one lens material and provides a good level of correction for chromatic aberrations in applications where the objective is used as a microlithography projection objective with a large image-side numerical aperture and a large image field. As the chromatic aberration increases with increasing bandwidth of the light used for the exposure, the restriction on the bandwidth of the exposure light can be relaxed only by using an objective with an exceptionally effective correction of the chromatic aberration, in particular the longitudinal chromatic aberration, without having to tolerate a deterioration in image quality.

The objective should be suited in particular for wavelengths of 157 nanometers and 193 nanometers. As an unexpected result, it was found that even with the complex boundary conditions imposed on a high-quality microlithography projection objective, measures can be taken with regard to the arrangement and the design of the lenses so that at a given amount of dispersion, a noticeable reduction of the

longitudinal chromatic aberration is achieved with a single lens material. Among the measures that can be taken, it has proven to be advantageous if positive refractive power is moved towards the image in order to keep the longitudinal chromatic aberration small.

The high-order Petzval correction that is necessary in lens arrangements of this type requires a design with waists of negative refractive power.

An arrangement where a doublet consisting of a positive lens and a negative lens is placed after the first waist with a large lens diameter of at least 85% of the maximum lens diameter or the maximum light bundle diameter provides the possibility to optimize the correction in regard to all aperture-related non-axial image aberrations without causing longitudinal chromatic aberrations.

Particularly the area ahead of the system diaphragm and the area of the diaphragm itself are predisposed to cause longitudinal chromatic aberrations. Because of this problem, it has proven to be advantageous to arrange lens doublets in the area ahead of and in the immediate vicinity of the system diaphragm, with each doublet having a positive lens coordinated

with a negative lens that is positioned close to the positive lens and has a similar light bundle diameter. Doublets with a combined refractive power of less than 20% of the refractive power between the diaphragm and the wafer were found particularly advantageous. The outside contour shape of the doublets resembles a thick curved meniscus that has a relatively small refractive power.

It has proven advantageous to provide a trace of a second waist in the form of two consecutive negative lenses placed between two positive lenses. Because of the large lens diameter of the negative lenses, the light bundle diameter is constricted only slightly in this second waist, in particular less than 10% of the maximum lens diameter occurring ahead of this waist. This has a beneficial effect on the longitudinal chromatic aberration.

Using aspheres in an opening group consisting of negative lenses has the advantage that the possibilities of the Petzval correction, in particular the field curvature correction, are not stretched to the limit.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following, the invention will be described in more detail based on specific embodiments, which represent examples and are not to be interpreted as limitations of the scope of the invention. The description refers to the attached drawings, wherein

Figure 1 represents a microlithography projection system;

Figure 2 represents a refractive projection objective with a length of 1340.7 mm and a numerical aperture of 0.8 for applications in microlithography with an exposure light wavelength of 193 nm;

Figure 3 represents a projection objective with a length of 1344 mm and a numerical aperture of 0.85 designed for a wavelength of 193 nm;

Figure 4 represents a projection objective with a length of 1390 mm and a numerical aperture of 0.85 designed for a wavelength of 157 nm;

Figure 5 represents a projection objective with a length of 1300 mm designed for a wavelength of 157 nm; and

Figure 6 represents a projection objective with a length of 1200 mm designed for a wavelength of 193 nm.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 1 serves to describe the principal layout of a projection system 1 for photographic exposures with a refractive projection objective 5. The projection system 1 has an illumination device 3 that is equipped with a means for narrowing the bandwidth. The projection objective 5 comprises a lens arrangement 21 with a system diaphragm 19, where the lens arrangement 21 defines an optical axis 7. A mask 9, which is held in the light path by means of a mask holder 11, is arranged between the illumination device 3 and the projection objective 5. Masks 9 of the kind used in microlithography carry a structure with detail dimensions in the micrometer to nanometer range, which is projected by means of the objective 5 onto an image plane 13 with a reduction in size by as much as a factor of 10, in particular a factor of 4. A substrate or wafer 15 is held in the image plane 13 by a substrate holder

17. The smallest detail dimensions of the structures that can be resolved in the image depend on the wavelength of the light used for the exposure and also on the numerical aperture of the projection objective 5 as well as a K-factor. The maximum level of resolution that can be achieved with the projection system 1 increases with smaller wavelengths of the light bundle 23 that is produced by the illumination device 3 and through which the pattern of the mask 9 is projected onto the wafer 15 by means of the projection objective 5.

The design of different lens arrangements 21 of projection objectives 5 for the wavelengths of 193 nm and 157.6 is described on the basis of Figures 2 to 6, with the terms projection objective and lens arrangement being used interchangeably.

The refractive lens arrangement 21 shown in Figure 2 is designed for the exposure light wavelength of 193 nanometers and has an image-side numerical aperture of 0.8. This lens arrangement 21 has 31 lenses, nine of which have at least one aspheric lens surface. This type of lens is also referred to as an asphere. The length from the object plane O to the image plane O' is 1340.7 mm.

The lens arrangement 21 of Figure 2 can be subdivided into three lens groups LG1 to LG3. The first lens group LG1 has a positive refractive power and includes the lenses with the surfaces 2-15. The lens group LG1, in turn, can be subdivided into an opening group EG1 which has negative refractive power and includes the first three lenses. The first two lenses on the object side have aspheres arranged on a convex lens surface on the side facing the object. These first two lenses are curved towards the object.

The lenses that follow the opening group EG1 form a bulge. These thick positive lenses have a favorable effect on the Petzval sum and also make a favorable contribution in regard to the coma correction. The last lens of the lens group LG1 has an aspherical surface on the side that faces towards the wafer.

The second lens group LG2 is made up of the lenses with the lens surfaces 16-21. The first and the last lens surface in this group are aspherical. The lens group has a negative refractive power and forms a distinct waist. Thus, this lens group makes a particularly valuable contribution to the correction of the higher-order sagittal spherical aberrations. At the same time, this lens group provides the main

contribution to the Petzval correction, in particular the flattening of the image curvature.

The second lens group is followed by the third lens group LG3, which is composed of the lenses with the lens surfaces 22-64. The most noticeable trait of this lens group is its elongated tubular appearance. This shape is the result of an elongated portion in the area ahead of the system diaphragm. This portion of the third lens group has a light bundle diameter or a lens diameter equal to at least 85% of the maximum lens diameter or the maximum light bundle diameter. Due to this configuration, it was possible to achieve favorable optical properties, particularly in regard to a longitudinal chromatic aberration, in an objective using only a single lens material. Especially the portion ahead of the system diaphragm 19 and the immediate vicinity of the system diaphragm are for principal reasons particularly critical sources of longitudinal chromatic aberration. In the illustrated example, four doublets are arranged ahead of the system diaphragm 19, each consisting of a positive lens and a negative lens. A further doublet consisting of a positive lens followed by a negative lens is arranged after the system diaphragm 19. A large portion of the refractive power of the objective is provided by a thick positive lens that follows after these doublets. An

end portion of the third lens group LG3, identified as UG3d in Figure 2 and composed of the lenses with the lens surfaces 31-54 has a favorable effect on the negative image distortion. The design of the end portion UG3d is essential in that it enables a very high aperture of 0.8 with an optimal degree of correction, because it contributes only to a small extent to the spherical aberration and coma.

A weakly curved waist of two successive negative lenses that are arranged ahead of the system diaphragm is identified as UG3b. The lenses with the lens surfaces 22-29, identified collectively as UG3a, form a positive subgroup that represents an atypical bulge.

The projection objective shown in Figure 2 allows an image field with an area of 10.5 x 26 mm^2 to be exposed, with the structure of the object being projected onto a wafer with a reduction factor of 4.

Table 1 represents the Code V™ data for the embodiment of the inventive objective that is illustrated in Figure 2.

TABLE 1

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
0	0.000000000	24.114319875	N2	1.00000320	56.080
1	0.000000000	3.482434220	N2	1.00000320	61.002
2	2078.963770280AS	11.540852046	SIO2HL	1.56028895	62.455
3	149.559792284	8.045820053	N2	1.00000320	63.745
4	283.335388909AS	10.384447026	SIO2HL	1.56028895	65.015
5	227.471174739	35.446688452	N2	1.00000320	66.284
6	-122.782367295	38.508940817	SIO2HL	1.56028895	68.210
7	-255.078934826	0.874570041	N2	1.00000320	89.183
8	-888.725542480	30.171005105	SIO2HL	1.56028895	95.735
9	-191.846579966	0.675200957	N2	1.00000320	98.735
10	640.397878968	41.049504805	SIO2HL	1.56028895	108.485
11	-250.387321692	0.675200957	N2	1.00000320	109.147
12	667.678997977	44.017612594	SIO2HL	1.56028895	105.073
13	-1125.455416998	0.675200957	N2	1.00000320	100.899
14	192.876693777	62.505832714	SIO2HL	1.56028895	93.072
15	331.893780633AS	32.604997110	N2	1.00000320	76.483
16	-171.193877443AS	17.084502546	SIO2HL	1.56028895	70.652
17	335.138365959	24.373437146	N2	1.00000320	66.301
18	-192.572424355	9.645727950	SIO2HL	1.56028895	65.926
19	418.847934941	26.888457292	N2	1.00000320	68.374
20	-140.483410076	10.610300745	SIO2HL	1.56028895	69.129
21	-459.758634782AS	16.193911170	N2	1.00000320	77.669
22	-188.260511338	24.787222412	SIO2HL	1.56028895	79.453
23	-123.558724879	1.174436845	N2	1.00000320	84.227
24	-224.101808279	35.439166118	SIO2HL	1.56028895	89.392
25	-158.235875230	1.137750024	N2	1.00000320	97.007
26	-244.923106839	26.771118597	SIO2HL	1.56028895	99.234
27	-435.595962845	19.019537360	N2	1.00000320	108.190
28	254.503542501	103.741855324	SIO2HL	1.56028895	125.704
29	-370.013146990	0.898100644	N2	1.00000320	123.190
30	-651.149669203AS	11.574873540	SIO2HL	1.56028895	119.614
31	346.341133415	40.118210584	N2	1.00000320	114.229
32	-378.937108427	11.574873540	SIO2HL	1.56028895	114.195
33	532.696677413	4.927372582	N2	1.00000320	118.682
34	439.556363278	74.374706500	SIO2HL	1.56028895	121.399
35	-502.601956332	0.675200957	N2	1.00000320	124.801
36	522.145069309AS	14.799644077	SIO2HL	1.56028895	124.414
37	1476.224552423	4.677319062	N2	1.00000320	124.271
38	2177.900420777	11.574873540	SIO2HL	1.56028895	124.349
39	384.316107261	1.595817333	N2	1.00000320	124.241
40	312.429605405	51.750696421	SIO2HL	1.56028895	125.681
41	-432.173779349	17.813396316	N2	1.00000320	125.439
42	-249.375527898	11.574873540	SIO2HL	1.56028895	124.719
43	-1589.233069199	14.468591925	N2	1.00000320	127.374
44	0.000000000	-4.822863975	N2	1.00000320	125.296
45	321.301154865	57.691242734	SIO2HL	1.56028895	131.351
46	-1054.206205699AS	14.951798157	N2	1.00000320	130.208
47	-589.044474927AS	11.574873540	SIO2HL	1.56028895	128.575
48	274.036317071	8.139476302	N2	1.00000320	128.119

TABLE 1 (continued)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
49	321.225611416	124.977354157	SIO2HL	1.56028895	129.264
50	-395.919230783	1.969428424	N2	1.00000320	131.721
51	820.198727366	26.845651259	SIO2HL	1.56028895	126.931
52	-973.939543882	0.694000123	N2	1.00000320	125.647
53	139.833041863	36.229940671	SIO2HL	1.56028895	107.077
54	242.551698933	0.867355440	N2	1.00000320	102.010
55	131.386059685	29.928967379	SIO2HL	1.56028895	91.857
56	235.274124558	0.675200957	N2	1.00000320	85.440
57	157.034314790	26.536117143	SIO2HL	1.56028895	79.168
58	231.201718823	9.219970606	N2	1.00000320	66.512
59	470.035875032	11.197726405	SIO2HL	1.56028895	61.464
60	236.045204498	0.675200957	N2	1.00000320	52.281
61	134.300351512	8.120819966	SIO2HL	1.56028895	48.003
62	63.666959363	10.716266548	N2	1.00000320	38.339
63	108.784923745	21.847901284	SIO2HL	1.56028895	35.245
64	693.402002382	8.681155155	N2	1.00000320	24.992
65	0.000000000	0.000000000	N2	1.00000320	14.020
66	0.000000000	0.000000000		1.00000000	14.020

ASPHERIC CONSTANTS

SURFACE NO. 2		SURFACE NO. 4		SURFACE NO. 15		SURFACE NO. 16	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	2.14106637e-007	C1	8.34485767e-008	C1	-2.63006449e-008	C1	3.25803022e-009
C2	-1.51669986e-011	C2	6.40722335e-012	C2	-2.79471341e-012	C2	-6.94860276e-013
C3	2.64769647e-015	C3	-1.82542397e-015	C3	-2.67096228e-016	C3	-1.78049294e-016
C4	-3.99036396e-019	C4	2.34304470e-019	C4	-1.35138372e-020	C4	-6.94438259e-021
C5	2.47505843e-023	C5	-8.26711198e-024	C5	-4.40665654e-024	C5	6.12556670e-024
C6	-3.15802350e-028	C6	-7.65863767e-028	C6	5.04322571e-028	C6	-1.48556644e-027
C7	3.03036722e-032	C7	6.41110903e-032	C7	-7.87867135e-032	C7	1.00088938e-031
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 21		SURFACE NO. 30		SURFACE NO. 36		SURFACE NO. 46	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	4.82674733e-008	C1	-1.45094804e-009	C1	-1.43259985e-008	C1	-7.44300951e-010
C2	1.36227355e-012	C2	5.04456796e-013	C2	-3.56045780e-013	C2	-1.00597848e-013
C3	-9.54833030e-017	C3	-5.09450648e-018	C3	-7.68193084e-018	C3	-1.16300854e-017
C4	9.50143078e-022	C4	-1.99406773e-022	C4	-1.87091119e-022	C4	3.24986044e-023
C5	5.69193655e-025	C5	-1.14064975e-026	C5	-1.28218449e-026	C5	5.82666461e-027
C6	-3.40684947e-029	C6	5.78307927e-031	C6	3.62372568e-031	C6	-4.12661445e-031
C7	2.94651178e-033	C7	-1.43630501e-035	C7	-2.39455297e-035	C7	6.25538499e-036
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 47

C0	0.0000
C1	-7.10390913e-009
C2	1.80939707e-014
C3	-1.34383300e-017
C4	-1.50233953e-023
C5	7.80860338e-027
C6	-4.98388772e-031
C7	9.26846573e-036
C8	0.00000000e+000
C9	0.00000000e+000

The following description relates to a further purely refractive lens arrangement 21 which is illustrated in Figure 3 and is likewise designed for light with a wavelength of 193 nm. The length of the lens arrangement 21, measured from the object plane O to the image plane O', is 1344.0 mm. A field of 10.5 x 26 mm^2 can be exposed. The lens arrangement of Figure 3 again has an opening group EG1 formed by the first lenses arranged on the object side, which are of negative refractive power. The subsequent lenses with the surfaces 8-15 form a lens group LG1. The last lens surface 15 of this lens group is again aspheric on the wafer side.

The subsequent lenses with the surfaces 16-21 form a third lens group LG2. This third lens group LG2 overall has a negative refractive power and forms a strongly curved waist 29. This lens group is followed by a fourth lens group LG3, which has an elongated tubular shape. A system diaphragm 19 is

arranged in this fourth lens group. On the side facing towards the third lens group LG2 and thus facing towards the object field, the fourth lens group LG3 has a subgroup UG3a with a small positive refractive power. This is followed by a weakly curved waist UG3b formed by two negative lenses with a large diameter equal to at least 85% of the maximum diameter. The two negative lenses belong to the doublets D1 and D2. There are two further doublets, identified as D3 and D4, arranged ahead of the system diaphragm 19. A further doublet is identified as D5 with aspheres on both of its surfaces 46 and 47. The final portion, identified as G3d, is made up of a plurality of thin lenses by which the wide light bundle 23 is focused onto the image plane, i.e., onto the wafer.

The image-side numerical aperture is 0.85. This objective projects the object into the image plane 13 with a reduction factor of 4. The data for all of the lenses are listed in Table 2.

TABLE 2

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
0	0.000000000	24.172413800	N2	1.00000320	56.080
1	0.000000000	15.006569837	N2	1.00000320	61.282
2	599.473674706AS	17.471359581	SIO2HL	1.56028895	65.688
3	142.945533106	15.594383723	N2	1.00000320	67.351
4	520.792476125AS	15.866311924	SIO2HL	1.56028895	70.201
5	458.213670894	35.531230748	N2	1.00000320	72.731
6	-130.942246277	29.261434955	SIO2HL	1.56028895	75.090
7	-522.434408367	1.046065674	N2	1.00000320	96.747
8	-6686.031621900	34.314309045	SIO2HL	1.56028895	103.359
9	-218.186494807	0.676827586	N2	1.00000320	106.388
10	706.363261168	45.122462397	SIO2HL	1.56028895	119.094
11	-278.472163674	0.676827586	N2	1.00000320	120.155
12	959.514633579	36.082624687	SIO2HL	1.56028895	118.383
13	-896.787607317	4.587825747	N2	1.00000320	116.762
14	158.750812726	85.801121037	SIO2HL	1.56028895	106.229
15	300.475102689AS	43.038670535	N2	1.00000320	83.117
16	-175.884377464A	6.768275864	SIO2HL	1.56028895	72.476
17	320.319576676	27.446116916	N2	1.00000320	68.293
18	-146.443321423	9.668965520	SIO2HL	1.56028895	67.974
19	339.454879151	28.665475857	N2	1.00000320	72.279
20	-161.977156970	10.635862072	SIO2HL	1.56028895	73.414
21	-238.647909042AS	15.370621050	N2	1.00000320	79.551
22	-150.311235300	27.766876031	SIO2HL	1.56028895	81.604
23	-155.362800581	0.676827586	N2	1.00000320	92.928
24	-428.765583246	34.936111184	SIO2HL	1.56028895	101.383
25	-220.472579824	0.676827586	N2	1.00000320	108.198
26	-438.752339375	25.651183289	SIO2HL	1.56028895	111.993
27	-486.537649387	16.665277911	N2	1.00000320	118.679
28	286.503340486	84.567562777	SIO2HL	1.56028895	136.363
29	-370.847311034	7.492580442	N2	1.00000320	135.394
30	-366.945132944AS	11.602758624	SIO2HL	1.56028895	132.013
31	577.586771717	32.431277232	N2	1.00000320	128.108
32	-559.674262738	11.602758624	SIO2HL	1.56028895	128.110
33	537.388094819	2.743298664	N2	1.00000320	131.720
34	408.077824696	42.484571757	SIO2HL	1.56028895	134.394
35	-717.357209302	0.676827586	N2	1.00000320	134.718
36	583.086197224AS	6.768275864	SIO2HL	1.56028895	133.965
37	269.271701042	7.352686536	N2	1.00000320	133.550
38	281.248185100	35.203322187	SIO2HL	1.56028895	136.018
39	472.606393970	3.186212988	N2	1.00000320	135.918
40	363.576248488	54.546183651	SIO2HL	1.56028895	137.633
41	-468.746315410	23.108875520	N2	1.00000320	137.324
42	-251.383937308	11.602758624	SIO2HL	1.56028895	136.437
43	-1073.133309030	33.841379320	N2	1.00000320	140.158
44	0.000000000	-24.172413800	N2	1.00000320	142.969
45	300.919916537	63.201252893	SIO2HL	1.56028895	150.411
46	-982.360166014AS	11.220067842	N2	1.00000320	149.618
47	-644.040642268AS	11.602758624	SIO2HL	1.56028895	148.330
48	251.499390884	13.548863209	N2	1.00000320	144.384

TABLE 2 (continued)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
49	295.116548681	83.834389825	SIO2HL	1.56028895	147.231
50	-592.936469041	0.676827586	N2	1.00000320	147.243
51	463.737108447	36.976613477	SIO2HL	1.56028895	141.167
52	-1426.895647680	0.695672042	N2	1.00000320	139.475
53	140.559527472	39.416922789	SIO2HL	1.56028895	113.157
54	220.743893827	0.878083956	N2	1.00000320	106.607
55	135.149194981	30.341942424	SIO2HL	1.56028895	96.272
56	227.528619088	0.689419669	N2	1.00000320	89.300
57	157.276474717	26.304510971	SIO2HL	1.56028895	82.536
58	236.864111032	8.994847659	N2	1.00000320	70.218
59	366.476934349	10.551547532	SIO2HL	1.56028895	63.779
60	98.334230915	0.676870172	N2	1.00000320	49.220
61	98.324175829	8.007759247	SIO2HL	1.56028895	48.802
62	76.949074769	8.603791096	N2	1.00000320	42.525
63	99.077661785	24.844220969	SIO2HL	1.56028895	39.131
64	511.945903814	8.702068968	N2	1.00000320	26.963
65	0.000000000	0.000000000	N2	1.00000320	14.020
66	0.000000000	0.000000000		1.00000000	14.020

ASPHERIC CONSTANTS

SURFACE NO. 2		SURFACE NO. 4		SURFACE NO. 15		SURFACE NO. 16	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	1.28169760e-007	C1	8.23267830e-008	C1	-7.43129292e-009	C1	-3.79251645e-008
C2	-7.84396436e-012	C2	2.76986901e-012	C2	-2.93262230e-012	C2	3.22483445e-012
C3	4.40001122e-016	C3	-1.95568740e-016	C3	-2.03722650e-016	C3	1.95986817e-016
C4	-7.79882973e-021	C4	-7.24098423e-021	C4	-1.22563860e-020	C4	2.59408631e-020
C5	-1.30623440e-023	C5	1.06376091e-023	C5	5.96520089e-025	C5	-1.79899203e-024
C6	2.14846923e-027	C6	-1.43486056e-027	C6	-1.46602552e-028	C6	-1.09069425e-029
C7	-1.41595024e-031	C7	1.06511374e-031	C7	1.53867443e-032	C7	3.19439367e-033
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 21		SURFACE NO. 30		SURFACE NO. 36		SURFACE NO. 46	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	-1.34732963e-008	C1	-2.23816289e-009	C1	-1.48722851e-008	C1	-1.29322449e-009
C2	2.75857068e-012	C2	6.79079206e-013	C2	-3.21783489e-013	C2	-7.13114740e-014
C3	1.90481938e-016	C3	-2.77226923e-018	C3	-1.94353769e-018	C3	-9.86341305e-018
C4	2.08472207e-020	C4	-1.25547219e-022	C4	-1.66369859e-022	C4	7.04573131e-023
C5	-6.19866674e-025	C5	-1.58964362e-026	C5	8.53060454e-028	C5	6.79406884e-027
C6	2.52896158e-028	C6	6.91621100e-031	C6	-4.40031159e-032	C6	-5.13273315e-031
C7	-1.80211827e-032	C7	-9.74826154e-036	C7	-1.13839635e-036	C7	8.48667932e-036
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 47

C0	0.0000
C1	-6.45902286e-009
C2	-2.38977080e-014
C3	-1.08609626e-017
C4	2.89713800e-023
C5	1.03658811e-026
C6	-6.18950334e-031
C7	1.10366044e-035
C8	0.00000000e+000
C9	0.00000000e+000

The lens arrangement illustrated in Figure 4 is designed to work with light of a wavelength of 157 nm (F2 excimer laser). The designed length, measured from the object plane O to the image plane O', is 1390.0 mm. A field of 10.5 x 26 mm^2 can be exposed with this lens arrangement 21. The overall configuration of this lens arrangement differs only in non-essential aspects from the arrangement of Figure 3, so that a detailed description would be redundant. The specific lens data are listed in Table 3.

TABLE 3

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 157.6299 nm	½ FREE DIAMETER
0	0.000000000	25.000000000	N2	1.00031429	59.000
1	0.000000000	15.339378260	N2	1.00031429	64.435
2	598.342471978AS	18.724519350	CAF2	1.55929035	69.077
3	48.181482862	16.454829635	N2	1.00031429	70.793
4	564.226137144AS	16.592649095	CAF2	1.55929035	73.697
5	465.197188245	36.842463522	N2	1.00031429	76.403
6	-136.836954878	30.276088945	CAF2	1.55929035	78.647
7	-551.745951642	1.159089824	N2	1.00031429	101.430
8	-9088.971563130	35.614698676	CAF2	1.55929035	108.594
9	-226.956823330	0.700000000	N2	1.00031429	111.475
10	723.679003959	46.740300924	CAF2	1.55929035	125.059
11	-289.614238561	0.700000002	N2	1.00031429	126.015
12	910.153581387	34.209584427	CAF2	1.55929035	124.006
13	-966.460684234	6.344682099	N2	.00031429	122.517
14	165.167813091	88.645251493	CAF2	1.55929035	110.777
15	311.690939161AS	44.560755800	N2	1.00031429	86.752
16	-181.953058549AS	7.000000001	CAF2	1.55929035	75.717
17	324.246438590	28.589730429	N2	1.00031429	71.205
18	-151.825774985	10.000000000	CAF2	1.55929035	70.907
19	355.946694253	29.718149685	N2	1.00031429	75.412
20	-167.034295485	11.000000000	CAF2	1.55929035	76.480
21	-246.225068997AS	15.900879213	N2	1.00031429	82.882
22	-155.088799672	28.774591277	CAF2	1.55929035	84.935
23	-160.065089727	0.718056461	N2	1.00031429	96.655
24	-441.811052729	36.169965537	CAF2	1.55929035	105.539
25	-228.522063652	0.700000001	N2	1.00031429	112.577
26	-454.136397771	26.566366602	CAF2	1.55929035	116.532
27	-500.119500379	17.199265008	N2	1.00031429	123.439
28	296.713551807	87.963677578	CAF2	1.55929035	141.803
29	-382.314123004	7.668609038	N2	1.00031429	140.780
30	-376.638593815AS	12.000000000	CAF2	1.55929035	137.274
31	607.216067418	33.641387962	N2	1.00031429	133.150
32	-570.164044613	12.000000000	CAF2	1.55929035	133.141
33	564.533373593	2.816684919	N2	1.00031429	136.871
34	427.721752683	43.902690083	CAF2	1.55929035	139.590
35	-732.675269060	0.700000000	N2	1.00031429	139.914
36	602.910545189AS	7.000000000	CAF2	1.55929035	139.079
37	279.908546327	7.662016814	N2	1.00031429	138.631
38	292.067625915	33.982510064	CAF2	1.55929035	141.194
39	486.808587823	3.734684777	N2	1.00031429	141.087
40	374.488854583	56.692816434	CAF2	1.55929035	142.952
41	-487.437697890	24.337612976	N2	1.00031429	142.631
42	-260.866697273	12.000000000	CAF2	1.55929035	141.625
43	-1117.259721160	35.000000000	N2	1.00031429	145.541
44	0.000000000	-25.000000000	N2	1.00031429	148.094
45	311.002273193	65.578230150	CAF2	1.55929035	157.034
46	-1023.554315350AS	11.481377894	N2	1.00031429	156.356
47	-672.576714992AS	12.000000000	CAF2	1.55929035	155.113
48	259.883468261	14.205528799	N2	1.00031429	151.262

TABLE 3 (cont.)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 157.6299 nm	½ FREE DIAMETER
49	305.263739591	86.781334194	CAF2	1.55929035	154.398
50	-617.755257115	0.700000000	N2	1.00031429	154.565
51	476.256251891	38.263167655	CAF2	1.55929035	148.491
52	-1486.494799770	0.719489630	N2	1.00031429	147.010
53	145.476122811	40.782858325	CAF2	1.55929035	119.019
54	229.665054801	0.933275871	N2	1.00031429	113.051
55	140.220419138	31.392645646	CAF2	1.55929035	101.740
56	234.824506571	0.723640009	N2	1.00031429	95.088
57	162.332837065	27.214899096	CAF2	1.55929035	87.541
58	244.278333665	9.299918126	N2	1.00031429	74.726
59	376.868342950	10.929551626	CAF2	1.55929035	67.902
60	101.455739030	0.715773254	N2	1.00031429	51.847
61	101.162965635	8.299519050	CAF2	1.55929035	51.361
62	79.437870675	8.884307252	N2	1.00031429	44.619
63	102.534993850	25.750482491	CAF2	1.55929035	41.066
64	527.160854703	9.000000000	N2	1.00031429	28.053
65	0.000000000	0.000000000	N2	1.00031429	14.750
66	0.000000000	0.000000000		1.00000000	14.750

ASPHERIC CONSTANTS

SURFACE NO. 2		SURFACE NO. 4		SURFACE NO. 15		SURFACE NO. 16	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	1.13998854e-007	C1	7.54224753e-008	C1	-6.96085201e-009	C1	-3.45865856e-008
C2	-6.36178693e-012	C2	2.18650725e-012	C2	-2.46245992e-012	C2	2.71322951e-012
C3	3.23659752e-016	C3	-1.43119795e-016	C3	-1.57870389e-016	C3	1.50235080e-016
C4	-5.32444727e-021	C4	-4.77106422e-021	C4	-8.75762750e-021	C4	1.89751309e-020
C5	-8.32495109e-024	C5	6.81749068e-024	C5	3.86817665e-025	C5	-1.30006219e-024
C6	1.27324768e-027	C6	-8.54589429e-028	C6	-9.00885871e-029	C6	6.16358831e-030
C7	-7.83910573e-032	C7	5.97164385e-032	C7	8.78630596e-033	C7	1.17159428e-033
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 21		SURFACE NO. 30		SURFACE NO. 36		SURFACE NO. 46	
C0	0.0000	C0	0.0000	C0	0.0000	C0	0.0000
C1	-1.29712266e-008	C1	-2.06288424e-009	C1	-1.34482120e-008	C1	-1.19258053e-009
C2	2.27339781e-012	C2	5.71589058e-013	C2	-2.70871166e-013	C2	-6.06323614e-014
C3	1.44782825e-016	C3	-2.21154944e-018	C3	-1.46625867e-018	C3	-7.79480128e-018
C4	1.49868277e-020	C4	-8.89810821e-023	C4	-1.23067852e-022	C4	5.18508440e-023
C5	-4.08871955e-025	C5	-1.08068385e-026	C5	6.79261614e-028	C5	4.67224846e-027
C6	1.55577307e-028	C6	4.36847400e-031	C6	-3.16281062e-032	C6	-3.31365069e-031
C7	-1.00785028e-032	C7	-5.73712694e-036	C7	-5.79252063e-037	C7	5.12625482e-036
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 47

C0	0.0000
C1	-5.81614530e-009
C2	-2.06494325e-014
C3	-8.58899622e-018
C4	2.06606063e-023
C5	7.14078196e-027
C6	-3.99032238e-031
C7	6.64567245e-036
C8	0.00000000e+000
C9	0.00000000e+000

The lens arrangement 21 shown in Figure 5 is designed likewise for the wavelength of 157.6 nm. This lens arrangement 21 differs significantly from the preceding examples in that only three doublets, i.e., D1, D2 and D4, are placed ahead of the system diaphragm 19. The doublet that was identified as D3 in the preceding figures has been omitted in the arrangement of Figure 5. The two consecutive negative lenses that form the second, weakly curved waist are in this case arranged at a distance from each other. As a result of the modified arrangement and the omission of the doublet D3, the lens volume of the objective is reduced, which has the benefits of a lower material cost and a reduced level of absorption. The specific lens data are listed in the following Table 4.

TABLE 4

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 157.6299 nm	½ FREE DIAMETER
0	0.000000000	23.762838750	N2	1.00031429	56.080
1	0.000000000	14.246137526	N2	1.00031429	61.246
2	514.707276562AS	13.981815236	CAF2	1.55929035	65.688
3	138.212721202	15.579876293	N2	1.00031429	66.951
4	534.824781243AS	12.739496641	CAF2	1.55929035	69.622
5	389.864179126	33.913726677	N2	1.00031429	71.684
6	-131.473719619	28.107831970	CAF2	1.55929035	73.586
7	-471.981433648	1.069906657	N2	1.00031429	93.899
8	0.000000000	34.308184523	CAF2	1.55929035	101.225
9	-228.280123150	0.704684075	N2	1.00031429	104.724
10	796.724829345	43.758159816	CAF2	1.55929035	116.173
11	-266.360318650	0.745094303	N2	1.00031429	117.347
12	1081.261439844	23.811542913	CAF2	1.55929035	115.969
13	-712.390784368	9.916731254	N2	1.00031429	115.443
14	158.258040233	80.929657183	CAF2	1.55929035	103.893
15	328.916333526AS	43.637981348	N2	1.00031429	83.021
16	-163.783184213AS	8.000000000	CAF2	1.55929035	71.477
17	294.432712383	27.405950067	N2	1.00031429	67.256
18	-144.330554051	8.234758928	CAF2	1.55929035	67.032
19	397.835892386	28.266532844	N2	1.00031429	71.373
20	-161.553948900	10.395325272	CAF2	1.55929035	72.890
21	-258.614401773AS	15.068965479	N2	1.00031429	79.201
22	-148.191144865	27.281969779	CAF2	1.55929035	80.726
23	-153.092043553	0.711404699	N2	1.00031429	91.935
24	-429.848987135	34.313214826	CAF2	1.55929035	100.580
25	-222.509319222	0.755186371	N2	1.00031429	107.422
26	-446.042338354	25.134410060	CAF2	1.55929035	111.325
27	-476.016743713	16.168036298	N2	1.00031429	117.862
26	290.945720195	91.150270987	CAF2	1.55929035	135.561
29	-352.999009021	7.239891532	N2	1.00031429	134.606
30	-333.990335846AS	10.794904282	CAF2	1.55929035	131.837
31	686.418617658	67.606049576	N2	1.00031429	128.953
32	484.704981071AS	20.247999550	CAF2	1.55929035	129.812
33	272.256910966	8.301324639	N2	1.00031429	129.690
34	283.424612963	21.444612905	CAF2	1.55929035	132.593
35	441.096441131	7.286378331	N2	1.00031429	132.611
36	341.080821148	56.120769051	CAF2	1.55929035	135.413
37	-467.022730717	23.483002796	N2	1.00031429	135.092
38	-251.271987182	10.033317804	CAF2	1.55929035	133.934
39	-1127.860216547	34.039044392	N2	1.00031429	137.435
40	0.000000000	-23.762838750	N2	1.00031429	140.287
41	297.718439650	63.279096400	CAF2	1.55929035	148.476
42	-917.492707769AS	10.913617063	N2	1.00031429	147.745
43	-614.308568323AS	11.278985347	CAF2	1.55929035	146.599
44	248.499662987	14.012163218	N2	1.00031429	143.454

TABLE 4 (continued)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 157.6299 nm	½ FREE DIAMETER
45	293.420324051	77.421679876	CAF2	1.55929035	146.721
46	-577.615924152	0.827697065	N2	1.00031429	146.976
47	428.803478030	38.627735627	CAF2	1.55929035	141.309
48	-1538.689777020	0.709093944	N2	1.00031429	539.590
49	138.430254604	39.259717130	CAF2	1.55929035	113.344
50	220.629434605	0.852226738	N2	1.00031429	107.642
51	134.960023432.	29.998458517	CAF2	1.55929035	97.026
52	215.500125113	0.702119104	N2	1.00031429	89.828
53	149.475551465	25.893987130	CAF2	1.55929035	82.702
54	231.671140781	8.806791935	N2	1.00031429	71.084
55	350.283305716	10.400580673	CAF2	1.55929035	64.558
56	145.109553410	0.700000000	N2	1.00031429	52.531
57	141.455177019	8.001279379	CAF2	1.55929035	51.711
58	73.955966022	8.329441414	N2	1.00031429	42.090
59	96.168359436	24.494556608	CAF2	1.55929035	38.879
60	459.800275735	8.554621950	N2	1.00031429	26.571
61	0.000000000		N2		14.020

ASPHERIC CONSTANTS

SURFACE NO. 2		SURFACE NO. 4		SURFACE NO. 15	
C0	0. 0000	C0	0. 0000	C0	0. 0000
CI	1.40076890e-007	CI	9.46620092e-008	C1	-1.23543806e-008
C2	-9.37770559e-012	C2	3.31455802e-012	C2	-3.08782621e-012
C3	5.50812946e-016	C3	-2.39290707e-016	C3	-2.03630284e-016
C4	6.20589318e-021	C4	-1.71234783e-020	C4	-8.16153110e-021
C5	-2.37140019e-023	C5	1.74026756e-023	C5	1.74407091e-025
C6	3.95180787e-027	C6	-2.43020107e-027	C6	-5.09307070e-029
C7	-2.60792832e-031	C7	1.77431459e-031	C7	1.00885745e-032
C8	0.00000000e+000	C8	0.00000000e+000	CB	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 16		SURFACE NO. 21		SURFACE NO. 30	
C0	0.0000	C0	0.0000	C0	0. 0000
C1	-4.62416977e-008	CI	-2.13181934e-008	C1	-2.44196650e-009
C2	5.09342413e-012	C2	3.39572804e-012	C2	6.83785083e-013
C3	1.93873865e-016	C3	1.70428863e-016	C3	-4.77483094e-018
C4	2.75889868e-020	C4	2.27977453e-020	C4	-4.35836087e-023
C5	-1.64807233e-024	C5	-9.47218587e-025	C5	-1.74046992e-026
C6	-1.89286552e-028	C6	2.65529506e-028	C6	6.83065300e-031
C7	1.58124115e-032	C7	-2.14888777e-032	C7	-9.01251572e-036
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 32		SURFACE NO. 42		SURFACE NO. 43	
C0	0.0000	C0	0.0000	C0	0.0000
Cl	-1.53715814e-008	C1	-1.38703825e-009	C1	-6.81804423e-009
C2	-3.53812954e-013	C2	-7.42014625e-014	C2	-3.12076075e-014
C3	-8.52862214e-019	C3	-1.11669633e-017	C3	-1.22481799e-017
C4	-2.84552357e-022	C4	7.72614773e-023	C4	2.99026626e-023
C5	3.34667441e-027	C5	8.16034068e-027	C5	1.23468742e-026
C6	-1.70981346e-031	C6	-6.36127613e-031	C6	-7.60144642e-031
C7	8.06815620e-038	C7	1.09104108e-035	C7	1.42018134e-035
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

The lens arrangement 21 shown in Figure 6 is designed for the wavelength of 193 nanometers. The size of the exposure field is 10.5 x 26 mm^2. The design length measured from the object plane O to the image plane O' is 1200 mm. An amount of only 103 kg of quartz glass material is required for manufacturing this objective. Analogous to the example of Figure 5, this embodiment again has a total of only four doublets. The doublet that was identified as D3 in Figures 2-4 has again been omitted in the arrangement of Figure 6. The detailed lens data are listed in Table 5.

TABLE 5

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
0	0.000000000	22.812325200	N2	1.00000320	56.080
1	0.000000000	10.339145912	N2	1.00000320	61.040
2	1344.886802290AS	15.881971169	SIO2HL	1.56028895	63.970
3	232.178777938	15.628670502	N2	1.00000320	66.074
4	-537.599235732AS	10.251256144	SIO2HL	1.56028895	67.146
5	357.600737011	39.221339825	N2	1.00000320	71.765
6	-107.956923549	18.404856395	SIO2HL	1.56028895	73.446
7	-243.717356229	0.700350683	N2	1.00000320	92.692
8	0.000000000	41.961272197	SIO2HL	1.56028895	108.723
9	-202.822623296	0.701099003	N2	1.00000320	112.352
10	908.396780928	46.105755859	SIO2HL	1.56028895	127.495

TABLE 5 (continued)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
11	-324.403526021	0.700000000	N2	1.00000320	129.122
12	272.374319621	70.961916034	SIO2HL	1.56028895	129.626
13	-861.339949580	0.801352132	N2	1.00000320	124.293
14	189.599720148	87.814706985	SIO2HL	1.56028895	107.193
15	235.651582170AS	33.939348010	N2	1.00000320	73.553
16	-167.950781585	23.127229402	SIO2HL	1.56028895	71.043
17	418.275060837AS	29.676213557	N2	1.00000320	66.843
18	-122.074492458	12.991654582	SIO2HL	1.56028895	65.012
19	225.914585773	27.597144000	N2	1.00000320	69.278
20	-207.944504375	9.625251661	SIO2HL	1.56028895	70.891
21	-222.237071915AS	12.259114879	N2	1.00000320	74.459
22	-143.306961785	25.742020969	SIO2HL	1.56028895	75.779
23	-171.350364563	0.700000000	N2	1.00000320	87.359
24	-584.950465544	30.430256525	SIO2HL	1.56028895	94.810
25	-322.926323860	0.700000000	N2	1.00000320	102.056
26	-2074.519592980	18.436325366	SIO2HL	1.56028895	106.932
27	-454.899324547	0.700000000	N2	1.00000320	108.765
28	311.973161398	60.379264795	SIO2HL	1.56028895	116.799
29	-244.157709436	4.226375511	N2	1.00000320	116.691
30	-226.802865587AS	8.000000000	SIO2HL	1.56028895	115.226
31	581.003793889AS	33.843695716	N2	1.00000320	113.965
32	433.165006354AS	8.000000000	SIO2HL	1.56028895	117.646
33	220.638014434	6.160147896	N2	1.00000320	117.478
34	235.847612538	38.094085109	SIO2HL	1.56028895	119.548
35	2922.562377140	10.091385703	N2	1.00000320	119.635
36	828.603251335	34.242333007	SIO2HL	1.56028895	120.292
37	-421.523524573	19.499093440	N2	1.00000320	120.075
38	-227.399216829	8.000000000	SIO2HL	1.56028895	119.391
39	-713.133778093	32.677482617	N2	1.00000320	122.273
40	0.000000000	-22.812325200	N2	1.00000320	124.721
41	477.077275979	54.887245264	SIO2HL	1.56028895	128.109
42	-302.959408554AS	9.015123458	N2	1.00000320	128.235
43	-259.248633314AS	8.000000000	SIO2HL	1.56028895	127.331
44	257.367927097	9.018964995	N2	1.00000320	132.095
45	301.442153248	62.427272391	SIO2HL	1.56028895	134.626
46	-415.709868667	0.700000000	N2	1.00000320	135.476
47	247.440229366AS	47.657128386	SIO2HL	1.56028895	133.887
48	-288949.445195000	0.700000000	N2	1.00000320	131.978
49	151.825283163	37.348129556	SIO2HL	1.56028895	112.363
50	293.987758399	0.700000000	N2	1.00000320	107.532
51	140.326981621	28.581518950	SIO2HL	1.56028895	94.765
52	219.719357959	0.700000000	N2	1.00000320	86.981
53	142.826791834	24.808199570	SIO2HL	1.56028895	79.406
54	283.110177788	7.914740800	N2	1.00000320	70.515
55	510.756323891	9.591341155	SIO2HL	1.56028895	64.645
56	266.825722219	0.722333492	N2	1.00000320	55.512
57	215.942664188	8.000000000	SIO2HL	1.56028895	53.165

TABLE 5 (continued)

SURFACE	RADIUS	THICKNESS	MATERIAL	REFR. INDEX 193.304 nm	½ FREE DIAMETER
58	72.787640467	7.718712927	N2	1.00000320	41.272
59	93.765259707	24.684737028	SIO2HL	1.56028895	38.377
60	469.355888001	8.212437072	N2	1.00000320	26.099
61	0.000000000	0.000000000	N2	1.00000320	14.020
62	0.000000000	0.000000000		1.00000000	14.020

ASPHERIC CONSTANTS

SURFACE NO. 2

C0	0.0000
C1	1.52757338e-007
C2	-1.39394902e-011
C3	7.41376692e-016
C4	-3.46945761e-019
C5	8.95992656e-023
C6	-1.64136955e-026
C7	1.18641735e-030
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 4

C0	0.0000
C1	4.00562871e-008
C2	4.60196624e-012
C3	-3.47640954e-016
C4	1.69507580e-019
C5	-3.89922208e-023
C6	7.79027536e-027
C7	-5.53241761e-031
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 15

C0	0.0000
C1	5.47524591e-008
C2	5.05793043e-013
C3	3.05008775e-017
C4	1.98253574e-021
C5	7.84443491e-025
C6	1.27239733e-028
C7	6.73733553e-033
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 17

C0	0.0000
C1	-9.99718876e-008
C2	-8.52059462e-012
C3	-5.86845398e-016
C4	-6.64124324e-020
C5	-4.60657771e-024
C6	-5.51712065e-028
C7	0.00000000e+000
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 21

C0	0.0000
C1	-1.77390890e-008
C2	1.86160395e-012
C3	2.57697930e-016
C4	2.73779514e-020
C5	4.36917581e-024
C6	-1.21030389e-028
C7	7.05508252e-032
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 30

C0	0.0000
C1	-2.92222111e-009
C2	6.98720386e-013
C3	9.60282132e-018
C4	4.51192034e-022
C5	-8.63764902e-026
C6	2.79307913e-030
C7	-4.28143587e-035
C8	0.00000000e+000
C9	0.00000000e+000

SURFACE NO. 31		SURFACE NO. 32		SURFACE NO. 42	
C0	0.0000	C0	0.0000	C0	0.0000
C1	3.79088573e-009	C1	-1.43835369e-008	C1	-1.46322720e-009
C2	1.54225743e-013	C2	9.53138635e-014	C2	-7.32982723e-014
C3	2.58122902e-018	C3	-7.72742465e-019	C3	-4.12559846e-018
C4	7.06529922e-022	C4	-5.55446815e-023	C4	1.10568402e-022
C5	-4.65550297e-026	C5	1.85136302e-026	C5	8.54286956e-027
C6	1.02837481e-030	C6	-1.44110574e-030	C6	-8.34588063e-031
C7	2.54076903e-036	C7	3.72591227e-035	C7	1.97309537e-035
C8	0.00000000e+000	C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000	C9	0.00000000e+000

SURFACE NO. 43		SURFACE NO. 47	
C0	0.0000	C0	0.0000
C1	-6.88182408e-009	C1	1.62217387e-009
C2	1.49845458e-014	C2	-6.74169300e-014
C3	-3.68264031e-018	C3	1.20108340e-018
C4	1.78132275e-022	C4	1.21664354e-023
C5	6.62312346e-027	C5	-1.11444071e-027
C6	-8.68541514e-031	C6	1.08479154e-031
C7	2.32817966e-035	C7	-2.93513997e-036
C8	0.00000000e+000	C8	0.00000000e+000
C9	0.00000000e+000	C9	0.00000000e+000

The aspheric lens surfaces in all of the foregoing examples are obtained by inserting the tabulated values for C_0, C_1, C_2, ... into the equation

$$P(h)=\frac{h^2/R}{1+\sqrt{1-(1+C_0)h^2/R^2}}+C_1h^4+C_2h^6+....$$

wherein P(h) represents the axial coordinate and h represents the radial coordinate of a point on the lens surface, i.e., P(h) indicates the distance of a point of the lens surface from

a plane that contains the vertex of the lens surface and extends perpendicular to the optical axis. C_1 to C_n are the aspherical constants listed in the tables, and the constant C_0 represents the conicity of the lens surface. R stands for the sagittal radius listed in the tables. The representation according to the foregoing equation with polynomial coefficients C_1 to C_n conforms to an industry standard known as CODE V™ and developed by Optical Research Associates, Pasadena, California.

Concerning the question of how big a loss in exposure contrast the photoresist can tolerate, it has been found that the contrast loss is significantly influenced by the longitudinal chromatic aberration of a lithography objective. In order to determine the bandwidth of a system for different apertures, wavelengths, materials and structure widths, it is proposed that the diameter of the circle of confusion induced by the longitudinal chromatic aberration be kept smaller than a factor of 2.2 times the structure width, and preferably even smaller than 2.0 times the structure width.

The chromatically induced circle of confusion is to be determined at the maximum aperture and for a deviation $\Delta\lambda$ from

the working wavelength by one-half the bandwidth of the light source.

In the following Table 6, the bandwidth of a system was determined for a case where the diameter of the chromatic circle of confusion was equal to 2.1 times the structure width. In comparison to a monochromatic system the resulting contrast loss in grid structures is about 6.5% with the polychromatic system.

Table 6

Embodiment	λ in nm	NA	Image field mm^2	Structure width [nm] K_1=0,32	Bandwidth pm	Material	CHL nm/pm	Number of aspheres	KCHL
Table 1	193	0,8	26x10,5	77,3	0,31	SiO	392	9	5,02
Table 2	193	0,85	26x10,5	72,8	0,24	SiO_2	401	9	5,13
Table 3	157	0,85	26x14	59,3	0,12	CaF_2	672	9	5,18
Table 4	157	0,85	26x10,5	59,3	0,12	CaF_2	668	9	5,15
Table 5	193	0,85	26x10,5	72,8	0,26	SiO_2	367	11	4,71
A*	248	0,83	26x8	95,8	0,75	SiO_2	180	4	6,07
B*	193	0,85	26x8	72,8	0,19	SiO_2	503	11	6,64

* A and B represent the respective embodiments of Table 2 and Table 4 of WO 01/50171 A1.

The structure width was determined according to the formula:

$$\text{Structure width} = \frac{\lambda * K_1}{NA},$$

wherein a value of 0.32 was selected for K_1. A practical range of variation for K_1 is between 0.27 and 0.35. The characteristic index KCHL can provide a comparison between the different designs of refractive lithography objectives with regard to the longitudinal chromatic aberration that occurs with the defined image field dimensions, light source band widths, and dispersion of the materials used in the lenses. If the objective consists of only one material, the dispersion of that single material is used. If the objective consists of a plurality of different materials, each lens is assigned a synthesized substitute material with the same refractive index as the actual material of that lens, but with a selected uniform dispersion for the calculation of the substitute longitudinal chromatic aberration.

$$KCHL = \frac{CHL[nm]}{\Delta\lambda[nm] * (\frac{\Delta n}{n-1}) * y`\max[nm]}, \text{ wherein}$$

CHL represents the longitudinal chromatic aberration,

$\Delta\lambda$ represents the bandwidth interval, and

Y'max represents the maximum image field diameter.

It is advantageous to enter the values for CHL, $\Delta\lambda$, Y'max in nm in the foregoing equation, choosing for example a value of 1 nm for $\Delta\lambda$. To document the state of the art, the examples A and B of, respectively, Table 4 and Table 2 of WO 01/50171 A1 are shown above in Table 6. Embodiment B has a highly typical KCHL-value of 6.07. Conventional refractive lithography objectives generally vary only within narrow limits from this amount, with the very high KCHL-value of 6.64 in embodiment A representing an exception.

KCHL-values falling significantly below 6.0 have been achieved for the first time with the embodiments presented herein. A particularly low KCHL-value of 4.71 was attained in the example of Table 5. This opens up the unprecedented possibility of using only quartz glass (fused silica, SiO_2) as lens material for a wavelength of 193 nm and a structure width of about 70 nm. The ability to completely eliminate the need for CaF_2 in an objective for 70 nm structures and to reduce the CaF_2 volume for structures smaller than 70 nm represents an enormous economic advantage. The objectives of the design proposed herein have a KCHL-value of less than 5.3, with a preference for KCHL-values below 5.0, and the strongest preference for KCHL-values below 4.8.

List of Reference Symbols

To the extent that the reference symbols indicate analogous elements, they are shared between the different drawing figures.

1	Projection system for photographic exposures
3	Illumination device
5	Projection objective
7	Optical axis
9	Mask
11	Mask holder
13	Image plane
15	Wafer
17	Substrate holder
19	System diaphragm
21	Lens arrangement
23	Light bundle
25	Maximum diameter of light bundle
27	Light bundle diameter
29	First waist